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CALIFORNIA UNIV SAN DIEGO LA JOLLA INST FOR PURE AND--ETC F/G 20/13
SUPERCONDUCTIVITY AND LATTICE INSTABILITIES.(U)
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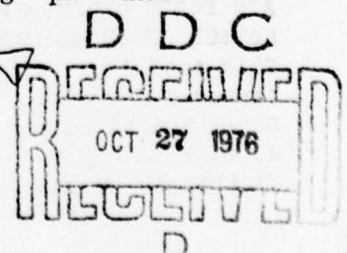
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SUPERCONDUCTIVITY AND LATTICE INSTABILITIES
CUMULATIVE WORK STATEMENT

F44620-72-C-0017

- a) Perform electric and magnetic measurements on metals and alloys.
- b) Determine the cause of metastabilities in metallic systems.
- c) Evaluate the effect of high pressures on the magnetic nature of the metallic state.
- d) Measure the influence of strain and its release on the superconducting transition temperature.
- e) Verify to the lowest temperature our hypothesis of superconductivity being the normal metallic behavior.
- f) Conduct investigations into the synthesis of unstable, metastable and stable metallic phases.
- g) Discover systems which will lead to metals having higher superconducting transitions.
- h) Exploit and expand recently discovered ternary compounds and phases of superconductors.
- i) Determine the cause and prevention of metastabilities in metallic systems.
- j) Explore the techniques of cladding, recrystallization by vapor catalysis, and high pressure for stabilizing metallic phases with higher superconducting transition temperatures.
- k) Explore the existence of metal-metal solid solution series.
- l) Develop the search for new ternary superconducting compounds.
- m) Discover new materials systems which will lead to more useful superconductors with enhanced physical, crystallographic and metallurgical properties.

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- n) Measure and characterize the superconducting properties of these materials.
- o) Synthesize new ternary, pseudobinary and quaternary metallic superconducting compounds.
- p) Increase the critical transition temperature of these materials.
- q) Study non cubic crystal structures with high critical temperatures.
- r) Investigate lattice instabilities and metastable phases in these superconducting materials.
- s) Measure and characterize the superconducting properties of these materials.

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(1) During the past five years we have discovered many new superconductors. Of these, the most important are lithium titanate, the Chevrel phases, new superconductors with the eta-carbide structure and new superconductors with the sodium-chloride structure.

Lithium titanate, when prepared with the spinel crystal structure, is superconducting at temperatures as high as 14 K.⁽¹⁾ This is the highest transition temperature known for any spinel structure compound, or, for that matter, any oxygen based compound. Lithium titanate also has the lowest known density of any potentially useful superconductor.

Lithium titanate seems to be one of those rare examples of ideosyncratic superconductivity in the sense that there exist no other superconducting compounds which are related both chemically and crystallographically. For this reason, all attempts to raise its transition temperature by means of chemical perturbation have failed, and for the same reason, we are at a loss to explain why the superconducting transition temperature should be so high in the first place. The superconductivity of lithium titanate thus illustrates what has become an important principle in the search for high temperature superconductors, namely that the existence and transition temperature of ternary compound superconductors cannot be predicted on the basis of the rules which have worked so well in the past for binary compound superconductors.

As it always has been, the search for new superconductors remains an empirical process.

Very important new ternary compound superconductors have been found among the so-called Chevrel phases.^(2, 3) These compounds may be thought of as highly distorted cesium chloride type structures, with one type of "atom" consisting of clusters of molybdenum and either sulfur, selenium or tellurium, while the other atom can be almost anything, e. g., copper, silver, tin, lead, zinc, cadmium, or one of the alkaline earths or even rare earths. So far, the highest transition temperatures are found for lead-molybdenum-sulfide at 15 K. While these temperatures, of course, are not the highest known today, the superconducting Chevrel phases do have enormous critical fields - as high as 700 kgauss.⁽⁴⁾ If these materials turn out to have favorable critical currents and mechanical properties, they will no doubt have important high field applications.

We have found that the Chevrel phases also have other properties which have never before been observed for any class of superconducting materials. One of these is the extraordinary sensitivity of their transition temperatures to applied hydrostatic pressure, which is the highest yet observed and is often nonlinear.⁽⁵⁾ It is believed that the origin of these effects is related to the fact that these compounds seem to be only marginally stable from a crystallographic point of view.

Another remarkable property of the Chevrel phases is their insensitivity to the incorporation of magnetic rare earth atoms into the crystal lattice. While for almost all other known superconductors the presence of a few atomic percent of, say, gadolinium would have a disastrous effect on the transition temperature, the effect of concentrations as high as seven percent seem to be very small in the Chevrel phases. For example, praseodymium-molybdenum selenide is superconducting well above 9°K and even gadolinium-molybdenum-selenide is superconducting near 6°K.⁽⁶⁾ In fact, the onset of magnetic order does not adversely affect the superconducting properties of the rare earth molybdenum selenides, and the magnetically ordered state seems to coexist quite happily with superconductivity at low temperatures.⁽⁷⁾ This state of affairs has only recently been discovered, and we do not yet have a full explanation; it is not unreasonable to expect that the phenomenon is somehow connected with the extraordinarily high values of the critical fields of the Chevrel phases.

However, the greatest challenge presented by the discovery of superconductivity in the Chevrel phases is its unpredictability. As with lithium titanate, there are no rules, such as the old electron concentration rules, for predicting the existence or transition temperature of superconductivity in these phases. With all the remarkable properties of the superconducting Chevrel phases, one would like to think that the process of discovery would be greatly accelerated by the application of new rules - which themselves are as yet undiscovered.

The superconductivity of the Chevrel phases has, of course, stimulated our interest in all kinds of chalcogenide materials. Many of the new superconductors discovered during the past five years have the sodium chloride structure. Among these we mention thorium-sulfide, thorium-selenide, scandium-sulfide, scandium-selenide and the related phosphides, zirconium phosphide, hafnium phosphide and thorium phosphide; the highest transition temperature (4.8 K) is observed for zirconium-phosphide.⁽⁸⁾ Transition temperatures up to 7 K were also observed in the pseudobinary system silver-tin-selenium with the sodium chloride structure.⁽⁹⁾

New ternary superconductors with the "eta-carbide" structure were found in the systems titanium-platinum-oxygen (2.5 K), zirconium-platinum-oxygen (5.4 K), hafnium-platinum-oxygen (2.2 K), niobium-zinc-carbon (4.6 K) and zirconium-vanadium-oxygen (5.5 K).⁽¹⁰⁾

The most interesting compound in this system is scandium-chromium-boron. Scandium and chromium by themselves do not even interact but with a few percent of boron as an impurity suddenly they form a superconducting intermetallic compound with transition temperatures in excess of 7° K.⁽¹¹⁾

(2) During the past five years we have obtained overwhelming evidence for a connection between moderate to high transition temperature superconductivity and low temperature structural instability.

Five years ago, only the two beta-tungsten structure superconductors niobium-tin and vanadium-silicon were known to undergo low temperature phase transitions and most people thought that these transformations were caused by properties unique to the beta-tungsten crystal structure. Now, on the contrary, we have shown that low temperature structural transformations occur in many superconductors with crystal structures entirely unrelated to the beta-tungsten structure. Table I shows the examples of this behavior which we have discovered here.

Table I

Material	Transition Temperature (°K)	Room Temperature Crystal Structure	Transformation Temperature (°K)	Low Temperature Crystal Structure	References
HfV ₂	8.4	Cubic Laves phase	118	Orthorhombic	12, 13
ZrV ₂	7.8	Cubic Laves phase	121	Rhombohedral	12, 14
LaRu ₂	4.5	Cubic Laves phase	30	Tetragonal	15
CuMo ₃ S ₄	10.9	Chevrel phase	260	Unknown	16
CuMo ₃ Se ₄	5.9	Chevrel phase	123	Unknown	17
ZnMo ₃ S ₄	3.0	Chevrel phase	57	Unknown	17

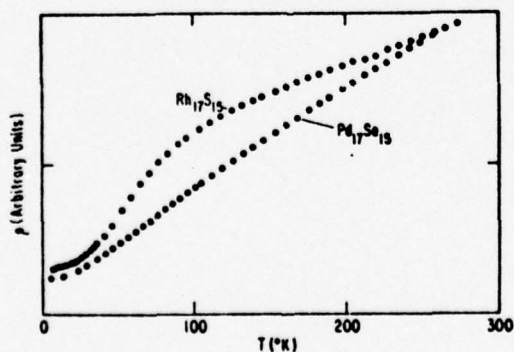
These compounds constitute approximately one third of all structurally unstable superconductors known today, and the discovery of their instability has contributed greatly to the current conventional wisdom that high temperature superconductivity and structural instability are intimately related. (18)

It was expected that the application of hydrostatic pressure would have rather dramatic effects on both the superconductivity and the transformation properties of structurally unstable superconductors. Pressure studies have been made on the systems vanadium-silicon,⁽¹⁹⁾ hafnium-vanadium,⁽²⁰⁾ zirconium-vanadium,⁽²⁰⁾ copper-molybdenum-sulfide,⁽⁵⁾ copper-molybdenum-selenide,⁽²¹⁾ zinc molybdenum sulfide,⁽⁵⁾ lanthanum sulfide,⁽²²⁾ lanthanum selenide,⁽²²⁾ vanadium-ruthenium,⁽²³⁾ and gold-zinc.⁽²⁴⁾ In every case the effects of pressure have been substantial (in some cases quite dramatic), but taken in the aggregate, the behavior of structurally unstable superconductors does not seem to follow any simple rule.

The effect of hydrostatic pressure has also been determined for most of the known Chevrel phases. In general, the effect is larger for this class of compounds than any other. We have concluded from these experiments that the superconducting Chevrel phases which do not show structural transformation have at least a latent instability. This point of view has been confirmed by recent Mössbauer spectroscopy⁽²⁵⁾ on tin-molybdenum-sulfide and neutron spectroscopy⁽²⁶⁾ on tin-molybdenum-sulfide and lead-molybdenum-sulfide.

(3) We have developed an empirical correlation between the shape of the electrical resistivity versus temperature curve of a given superconductor and its transition temperature.

During the past five years we have measured the electrical resistivity as a function of temperature for many metallic compounds, both superconducting and non-superconducting. As a result of these measurements we have found that, provided one of the constituents is a transition metal, a strong correlation exists between the shape of the resistivity-temperature curve and the transition temperature of the compound under study. Briefly stated, the correlation is that the resistivity-temperature curves of transition metal non-superconductors are always concave upward (positive curvature), while the resistivity-temperature curves of transition metal superconductors are always concave downward (negative curvature).⁽²⁷⁾ As an example, the resistivity-temperature curves for isostructural rhodium-sulfide and palladium-selenide are shown below. Rhodium-sulfide is superconducting at 5.8 K and shows strong negative curvature, while palladium-selenide is not superconducting above 1.0 K and shows hardly any curvature at all.



Further examples include the copper dialuminide phases (zirconium-rhodium, zirconium-iridium, zirconium-nickel and zirconium-cobalt) where correlations with specific heat data are obtained,⁽²⁸⁾ and alloys between the cubic Laves phases lanthanum-ruthenium and cerium-ruthenium for which the superconducting transition temperature and the degree of curvature are strongly correlated.⁽²⁹⁾

Our discovery that the negative curvature of the resistivity-temperature curves of transition metal superconductors is an extremely general phenomenon has provoked a great deal of theoretical discussion. The results are not at all explained by established theories for the electrical resistivity (Bloch-Grüneisen theory, as modified by Wilson), and further modifications of the theory to include temperature induced motion of the Fermi level or lattice softening at low temperatures have not led to agreement between experiment and theory. Since the electron-lattice interaction which gives rise to the existence of electrical resistivity is also responsible for superconductivity, we feel that the puzzle of negative curvature in the resistance-temperature curves of superconductors is an important one which should not be allowed to remain unsolved. This is especially true since the measurement of electrical resistivity is a relatively simple one and can be performed on almost all materials -- and what is probably one of the most crucial features -- at temperatures far above the superconducting transition

(4) We have extrapolated to the transition temperatures of magnesium and gold. These experiments consisted of measuring the superconductivity of highly purified alloys of magnesium-cadmium, gold-aluminum, gold-indium and gold-gallium at temperatures as low as 0.007 K and extrapolating to the values of the transition temperature of pure magnesium and pure gold. As a result, we predict that pure magnesium will become superconducting at 0.0004 K,⁽³⁰⁾ and pure gold will do so at 0.0002 K.⁽³¹⁾ Of course, these predictions will be fulfilled only when such low temperatures can be reached, and sufficiently pure samples of these elements are available.

The value of these low temperature experiments is that our understanding of superconductivity with respect to the periodic system - our only real guidance in the search for high temperature superconductivity - is thereby extended.

References

1. D. C. Johnston, H. Prakash, W. H. Zachariasen and R. Viswanathan, High Temperature Superconductivity in the Li-Ti-O Ternary System, *Mat. Res. Bull.* 8, 777 (1973).
2. Bernd T. Matthias, High Transition Temperature Ternary Superconductors, *Proc. 13th Inter. Conf. on Low Temp. Phys.*, Boulder, Colorado, 1972, eds. K. D. Timmerhaus, W. J. O'Sullivan and E. F. Hannel (Plenum Press, N.Y., London, 1974), p. 416.
3. R. W. McCallum and H. Adrian, Superconductivity in Rare Earth Molybdenum Selenides, *Phys. Letters* 56A, 213 (1976).
4. Ø. Fischer, M. Decroux, S. Roth, R. Chevrel and M. Sergent, Compensation of the Paramagnetic Effect on H_{c2} by Magnetic Moments: 700 kGauss, to be published in *J. Phys. F: Metal Physics*.
5. R. N. Shelton, A. C. Lawson and D. C. Johnston, Pressure Dependence of the Superconducting Transition Temperature for Ternary Molybdenum Sulfides, *Mat. Res. Bull.* 10, 297 (1975).
6. R. W. McCallum and H. Adrian, Superconductivity in Rare Earth Molybdenum Selenides, *Phys. Letters* 56A, 213 (1976).
7. R. W. McCallum, D. C. Johnston, R. N. Shelton and M. B. Maple, Calorimetric Observation of a Phase Transition in the Superconducting State in $Gd_{1.2}Mo_6Se_8$, *Proc. Conf. on Superconductivity in d- and f-Band Metals*, ed. David H. Douglass, Rochester, N. Y. (1976) (in press).
8. A. R. Moodenbaugh, D. C. Johnston and R. Viswanathan, Superconductivity in Two NaCl Structure Compounds: α -ZrP and ScS_{1-x} , *Mat. Res. Bull.* 9, 1671 (1974).
9. D. C. Johnston and H. Adrian, Superconducting and Normal State Properties of $Ag_{1-x}Sn_{1+x}Se_{2-y}$, *J. Phys. Chem. Sol.* (in press).
10. D. C. Johnston, D. E. Moncton and A. C. Lawson, unpublished results.
11. J. M. Vandenberg, B. T. Matthias, E. Corenzwit and H. Barz, Superconductivity of a New Metastable Phase of Scandium-Chromium, *J. Sol. State Chem.* (in press).

12. A. C. Lawson, More Soft Superconductors: ZrV_2 and HfV_2 , Phys. Lett. 36A, 8 (1971).
13. A. C. Lawson and W. H. Zachariasen, Low Temperature Lattice Transformation of HfV_2 , Phys. Letters 38A, 1 (1972).
14. D. E. Moncton, Lattice Transformation in the Superconductor ZrV_2 by Neutron Diffraction, Sol. State Commun. 13, 1779 (1973).
15. A. C. Lawson, E. Engel and K. Baberschke, Low Temperature Lattice Transformation of LaRu_2 , Phys. Letters A48, 107 (1974).
16. A. C. Lawson, Lattice Instabilities in Superconducting Ternary Molybdenum Sulfides, Mat. Res. Bull. 7, 773 (1972).
17. R. N. Shelton and A. C. Lawson, unpublished results.
18. A. C. Lawson and R. N. Shelton, Lattice Instability in Non-A-15 Superconductors, Ferroelectrics (in press).
19. R. N. Shelton and T. F. Smith, Pressure Dependence of T_c and Phase Stability for V_3Si , Mat. Res. Bull. 10, 1013 (1975).
20. T. F. Smith, R. N. Shelton and A. C. Lawson, Superconductivity and Structural Instability of $(\text{Hf}, \text{Zr})\text{V}_2$ and $(\text{Hf}, \text{Ta})\text{V}_2$ Alloys at High Pressures, J. Phys. F: Metal Phys. 3, 2157 (1973).
21. R. N. Shelton, The Effect of High Pressure on Superconducting Ternary Molybdenum Chalcogenides, Proc. Conf. on Superconductivity in d- and f-Band Metals, ed. David H. Douglass, Rochester, N. Y. (1976) (in press).
22. R. N. Shelton, A. R. Moodenbaugh, P. D. Dernier and B. T. Matthias, The Effect of Pressure on the Superconducting and Crystallographic Transition of La_3S_4 , La_3Se_4 and La_3Te_4 , Mat. Res. Bull. 10, 111 (1975).
23. T. F. Smith, R. N. Shelton, A. C. Lawson and C. W. Chu, Superconductivity and Stability of Near-Equi-Atomic V-Ru Compounds at High Pressure, J. Phys. F: Metal Phys. 4, 1423 (1974).
24. B. T. Matthias, E. Corenzwit, J. M. Vandenberg, H. Barz, M. B. Maple and R. N. Shelton, Obstacles to Superconductivity in CsCl Phases, J. Less Common Metals 35, 339 (1976).

25. C. W. Kimball, L. Weber, G. Van Landuyt, F. Y. Fradin, B. D. Dunlap and G. K. Shenoy, Lattice Softening and Anisotropy at ^{119}Sn Sites in SnMo_6S_8 , Phys. Rev. Lett. 36, 412 (1976).
26. S. D. Bader, S. K. Sinha and R. N. Shelton, Inelastic Neutron Scattering Studies of the Phonon Spectra of Chevrel Phase Superconductors, Proc. Conf. on Superconductivity in d- and f-Band Metals, ed. David H. Douglass, Rochester, N. Y. (1976) (in press).
27. Z. Fisk and A. C. Lawson, Normal State Resistance Behavior and Superconductivity, Sol. State Commun. 13, 277 (1973).
28. Z. Fisk, R. Viswanathan and G. W. Webb, The Relation between Normal State Properties and T_c for Some Zr_2S Compounds, Sol. State Commun. 15, 1797 (1974).
29. A. C. Lawson, K. Baberschke and U. Engel, Normal State Electrical Resistance Behavior and Superconducting Transition Temperatures in $(\text{La}, \text{Ce})\text{Ru}_2$ Alloys, Phys. Letters A49, 373 (1974).
30. A. C. Mota, P. Brewster and R. Wang, Superconductivity in the Mg-Cd System: Extrapolated T_c for Pure Magnesium, Phys. Letters 41A, 99 (1972).
31. A. C. Mota and R. F. Hoyt, Dependence of the Superconducting Transition Temperature on Electron per Atom Ratio and Lattice Deformation in Noble Metal Alloys, Sol. State Commun. (in press).

Publication List -- 10/1/71 - 9/30/76

1. Higher Temperatures and Instabilities, Bernd T. Matthias, Proc. AIP Conf. #4 Superconductivity in d- and f-Band Metals, Rochester, N.Y., Oct. 1971; Ed. David H. Douglass, N.Y., 1972, p. 367.
2. Spin Excitation Effects in Superconductors, M. B. Maple, Proc. AIP Conf. #4 Superconductivity in d- and f-Band Metals, Rochester, N.Y., Oct. 1971; Ed. David H. Douglass, N.Y., 1972, p. 175.
3. Determination of Pressure Dependence of T_c for d and f Band Superconductors, T. F. Smith, Proc. AIP Conf. #4 Superconductivity in d- and f-Band Metals, Rochester, N.Y., Oct. 1971; Ed. David H. Douglass, N.Y., 1972, p. 273.
4. Comparison between Ferromagnetism and Superconductivity in Intercalation Compounds, Bernd T. Matthias, Physics Letters 37A, 249 (Oct. 1971).
5. From Barium Titanate to DNA, Bernd T. Matthias, Materials Research Bulletin 6, 1005 (Oct. 1971).
6. A New Procedure for Qualitative X-ray Analysis with Electron Excitation, J. Z. Frazer, H. Fujita and R. W. Fitzgerald, Materials Research Bulletin 6, 711 (Oct. 1971).
7. Superconducting Isotope Effect in ZrB_{12} , Z. Fisk, A. C. Lawson, B. T. Matthias, and E. Corenzwit, Physics Letters 37A, 251 (Nov. 22, 1971).
8. Superconductivity and Magnetic Susceptibility Studies of the Cubic Laves Phase Alloys $CeRu_{2-x}Co_x$, T. F. Smith, H. L. Luo, M. B. Maple and I. R. Harris, Journal of Physics F, Metal Physics 1, 896 (Nov. 1971).
9. Superconductivity of $AlMn$ and ThU Alloys under Pressure, J. G. Huber and M. B. Maple, Journal of Physics F, Metal Physics 1, 893 (Nov. 1971).
10. Thermodynamics of Pressure Effects in V_3Si and V_3Ge , L. J. Sham and T. F. Smith, Physical Review 4B, 3951 (Dec. 1, 1971).
11. Hyperfine Splitting in the Electron Spin Resonance of Dy and Er in the Transition Metal-Rh, D. Davidov, R. Orbach, C. Rettori, D. Shaltiel, L. J. Tao and B. Ricks, Physics Letters 37A, 361 (Dec. 6, 1971).

12. Destruction of Ferromagnetism in ZrZn_2 at High Pressure, T. F. Smith, J. A. Mydosh, and E. P. Wohlfarth, *Physical Review Letters* 27, 1732 (Dec. 20, 1971).
13. A Convenient and Reliable Demountable Seal for Low Temperature Work, A. C. Mota, *Review of Scientific Instruments* 42, 1541 (1971).
14. Magnetic-Nonmagnetic Transition in Alloys with Cerium Impurities, B. Coqblin, M. B. Maple and G. Toulouse, *International Journal of Magnetism* 1, 333 (1971).
15. Application of the Faraday Method to Magnetic Measurements under Pressure, D. Wohlleben and M. B. Maple, *Review of Scientific Instruments* 42, 1573 (1971).
16. Low Temperature Lattice Transformation of HfV_2 , A. C. Lawson and W. H. Zachariasen, *Physics Letters* 38A, 1 (Jan. 3, 1972).
17. The Superconductivity of Double Chalcogenides: $\text{Li}_x\text{Ti}_{1.1}\text{S}_2$, H. Barz, A. S. Cooper, E. Corenzwit, M. Marezio, B. T. Matthias and P. H. Schmidt, *Science* 175, 884 (Feb. 25, 1972).
18. Superconducting Transition Temperature and Magnetic Susceptibility of Polycrystalline α -Uranium under Pressure, M. B. Maple and D. Wohlleben, *Physics Letters* 38A, 351 (Feb. 28, 1972).
19. Electron Spin Resonance of Rare Earth Ions in the Actinide Cubic Metal Th, D. Davidov, R. Orbach, C. Rettori, D. Shaltiel, L. J. Tao, and B. Ricks, *Physical Review* B5, 1711 (Mar. 1, 1972).
20. Lattice Instabilities and Superconductivity of $(\text{Hf}, \text{Ta})\text{V}_2$ and $(\text{Hf}, \text{Zr})\text{V}_2$ Alloys, A. C. Lawson, *Physics Letters* 38A, 379 (Mar. 13, 1972).
21. Pressure Dependence of the Superconducting Transition Temperature of Thorium, W. A. Fertig, A. R. Moodenbaugh, and M. B. Maple, *Physics Letters* 38A, 517 (Mar. 27, 1972).
22. High Temperature Superconductors, The First Ternary System, B. T. Matthias, M. Marezio, E. Corenzwit, A. S. Cooper, and H. E. Barz, *Science* 175, 1465 (Mar. 31, 1972).
23. Materials for Electricity and Magnetism, Advanced Material Usage in the Southwest, Bernd T. Matthias, National Commission on Materials Policy Conference, June 12-16, 1972 (Lake Arrowhead, Calif.)
24. Heat Capacity of Superconducting Ternary Molybdenum Sulfides, R. Viswanathan and A. C. Lawson, *Science* 177, 267 (July 12, 1972).

25. Rare Earth Manganese and Cobalt Oxide Catalysts Rival Platinum for Auto Exhaust Treatment, R. J. H. Voorhoeve, J. P. Remeika, P. E. Freeland and B. T. Matthias, *Science* 177, 353 (July 28, 1972).
26. Electron Spin Resonance of Dy and Er in Ir, D. Davidov, R. Orbach, C. Rettori, L. J. Tao and B. Ricks, *Physics Letters* 40A, 269 (July, 31, 1972).
27. Lattice Instabilities in Superconducting Ternary Molybdenum Sulfides, A. C. Lawson, *Materials Research Bulletin* 7, 773 (Aug. 1972).
28. Superconductivity in the Mg-Cd System: Extrapolated T_c for Pure Magnesium, A. C. Mota, P. Brewster and R. Wang, *Physics Letters* 41A, 99 (Sept. 11, 1972).
29. The Re-entrant Superconducting-Normal Phase Boundary of the Kondo System (La, Ce)Al₂, M. B. Maple, W. A. Fertig, A. C. Mota, L. E. DeLong, D. Wohlleben and R. Fitzgerald, *Solid State Communications* 11, 829 (Sept. 15, 1972).
30. Pressure Dependence of the Superconducting Transition Temperature for Vanadium, T. F. Smith, *Journal of Physics F, Metal Physics* 2, 946 (Sept. 1972).
31. Superconducting Ion Beam Sputtered Chromium Metal Thin Films, P. H. Schmidt, R. N. Castellano, H. Barz, B. T. Matthias, J. G. Huber and W. A. Fertig, *Physics Letters* 41A, 367 (Oct. 9, 1972).
32. Zr_{3+x}S₄: A New Superconducting Binary Sulfide, D. C. Johnston and A. Moodenbaugh, *Physics Letters* 41A, 447 (Oct. 23, 1972).
33. Specific Heat of the Superconducting Kondo System (La, Ce)Al₂, C. A. Luengo, M. B. Maple and W. A. Fertig, *Solid State Communications* 11, 1445 (Nov. 15, 1972).
34. Low Temperature Specific Heat of ThU, C. A. Luengo, J. M. Cotingnola, J. Sereni, A. R. Sweedler, M. B. Maple and J. G. Huber, *Solid State Communications* 10, 459 (1972).
35. Superconductivity at High Pressure in the A-15 Compounds, T. F. Smith, *Journal of Low Temperature Physics* 6, 171 (1972).
36. Superconductivity of NbSe₂ to 140 kbar, T. F. Smith, L. E. DeLong, A. R. Moodenbaugh, T. H. Geballe and R. E. Schwall, *Journal of Physics C*, 5, L230 (1972).

37. Magnetization Curves of Superconductors--Type I, Type II, and Type III, Bernd T. Matthias, Proceedings of 1972 Proton Linear Accelerator Conference.
38. On the Pressure Dependence of the Transition Temperature of Superconductors with Ce Impurities, M. B. Maple, Physics Letters 42A, 247 (1972).
39. Superconductivity in 1971, Bernd T. Matthias, International Journal of Quantum Chemistry 6, 429 (1972).
40. Superconductivity in the Pseudo-binary A-15 Compounds $\text{Mo}_3\text{Os}_{1-x}\text{Ru}_x$ and $\text{Mo}_3\text{Ir}_{1-x}\text{Ru}_x$, David C. Johnston, Solid State Communications 11, 1751 (1972).
41. Superconductivity of Solid Solutions of Re with Mo_2C , W. Mons, Ch. J. Raub and A. C. Lawson, Journal of Less Common Metals 26, 319 (1972).
42. Magnetic Properties of TmTe at the Pressure-Induced Electronic Phase Transition, D. Wohlleben, J. G. Huber and M. B. Maple, Proceedings of the 17th Annual Conference on Magnetism and Magnetic Materials, AIP, New York (1972), pp. 1478.
43. Electron Spin Resonance of Rare Earths in Aluminum, C. Rettori, D. Davidov, R. Orbach, E. P. Chock and B. Ricks, Physical Review 7B, 1 (Jan. 1, 1973).
44. Specific Heat of the $(\text{La}, \text{Gd})\text{Al}_2$ System in the Superconducting and Normal State, C. A. Luengo and M. B. Maple, Solid State Communications 12, 757 (April 15, 1973).
45. The Electrical Resistivity of Barium and Yttrium at High Pressure, A. R. Moodenbaugh and Z. Fisk, Physics Letters 43A, 479 (April 23, 1973).
46. Thermal Contact between $\text{Na}_3 [\text{Ce}(\text{C}_7\text{H}_3\text{NO}_4)_3] \cdot 15\text{H}_2\text{O}$ and Liquid He^3 at Millikelvin Temperatures, J. H. Bishop and A. C. Mota, Physics Letters 43A, 511 (April 23, 1973).
47. Superconductivity of LaOs_2 , A. C. Lawson, John F. Cannon, Donald L. R. Robertson and H. Tracy Hall, Journal of Less Common Metals 32, 173 (April 1973).
48. High Temperature Superconductivity, B. T. Matthias, La Recherche 4, 319 (April 1973).

49. Thermal Decomposition of PrCo_2 and NdCo_2 under Ultra-High Vacuum, P. D. Farmar and A. C. Lawson, *Physics Letters* 44A, 1 (May 7, 1973).
50. Influence of Fermi Surface Topology upon the Pressure Dependence of T_c for Indium and Dilute Indium Alloys, T. F. Smith, *Journal of Low Temperature Physics* 11, 581 (June 1973).
51. Magnetic to Nonmagnetic Transition of Cerium Impurities in (La,Th) Alloys, S. Ortega, M. Roth, C. Ruzzuto and M. B. Maple, *Solid State Communications* 13, 5 (July 1, 1973).
52. Normal State Resistance Behavior and Superconductivity, Z. Fisk and A. C. Lawson, *Solid State Communications* 13, 277 (Aug. 1, 1973).
53. Cooperative Phenomena and Dimensionality, Bernd T. Matthias, *Journal of Vacuum Science Technology* 10, 753 (Sept./Oct. 1973).
54. Criteria for Superconducting Transition Temperatures, Bernd T. Matthias, *Physics* 69, 54 (Oct. 1973).
55. Pressure Dependence of T_c for $(\text{Au}_{1-x}\text{Pd}_x)\text{Ga}_2$ Alloys, T. F. Smith, R. N. Shelton and J. E. Schirber, *Physical Review* B8, 3479 (Oct. 1973).
56. The Relation between Normal State Properties and T_c for Some Zr_2X Compounds, Z. Fisk, R. Viswanathan and G. W. Webb, *Solid State Communications* 15, 1797 (Dec. 15, 1973).
57. Superconductivity and Structural Instability of $(\text{Hf}, \text{Zr})\text{V}_2$ and $(\text{Hf}, \text{Ta})\text{V}_2$ Alloys at High Pressures, T. F. Smith, R. N. Shelton and A. C. Lawson, *Journal of Physics F, Metal Physics* 3, 2157 (Dec. 1973).
58. The Physical Properties of a Superconducting Ternary Sulfide $\text{Ag}_2\text{Pd}_3\text{S}$, H. R. Khan, H. Trunk, Ch. J. Raub, W. A. Fertig and A. C. Lawson, *Journal of Less Common Metals* 30, 169 (1973).
59. Superconductivity in the High Pressure Phases of Barium, A. R. Moodenbaugh and J. Wittig, *Journal of Low Temperature Physics* 10, 203 (1973).
60. Formation of Local Magnetic Moments in Metals: Experimental Results and Phenomenology, D. K. Wohlleben and B. R. Coles, *MAGNESTISM: A Treatise on Modern Theory and Materials*, Vol. V. ed. H. Suhl (Academic Press, N.Y., 1973), Chapter 10.

61. Paramagnetic Impurities in Superconductors, M. B. Maple, *MAGNETISM: A Treatise on Modern Theory and Materials*, Vol. V, ed. H. Suhl (Academic Press, N.Y., 1973), Chapter 10.
62. Transition Temperatures of Superconductors, Bernd T. Matthias, *Cooperative Phenomena*, eds. H. Haken and M. Wagner, Springer-Verlag (1973), p. 94.
63. Thermal Contact between Cerium Magnesium Nitrate and Liquid He^3 at Very Low Temperatures, J. H. Bishop, D. W. Cutter, A. C. Mota and J. C. Wheatley, *Journal of Low Temperature Physics* 10, 379 (1973).
64. The Effect of High Pressure on the Crystal Structure of LaOs_2 and CeOs_2 , John F. Cannon, Donald L. Robertson, H. Tracy Hall and Angus C. Lawson, *Journal of Less Common Metals* 31, 174 (1973).
65. Stabilization of the Cubic A-15 Phase of Nb_3Sn , R. Viswanathan and D. C. Johnston, *Materials Research Bulletin* 8, 589 (1973).
66. Magnetic Ordering in $(\text{La}, \text{Gd})\text{Al}_2$ Alloys, M. B. Maple, *Solid State Communications* 12, 653 (1973).
67. Superconductivity in 1972, Bernd T. Matthias, *International Journal of Quantum Chemistry* 7, 659 (1973).
68. High Temperature Superconductivity in the Li-Ti-O Ternary System, D. C. Johnston, H. Prakash, W. H. Zachariasen and R. Viswanathan, *Materials Research Bulletin* 8, 777 (1973).
69. Superconductivity and Phase Transitions in Single Crystal and Polycrystal $\alpha\text{-U}$ at High Pressure, T. F. Smith and E. S. Fisher, *Journal of Low Temperature Physics* 12, 631 (1973).
70. The Superconducting Isotope Effect of Iron in U_6Fe , J. J. Engelhardt, *Solid State Communications* 13, 1355 (1973).
71. Superconductivity and Phase Stability of Selenium at High Pressures, A. R. Moodenbaugh, C. T. Wu and R. Viswanathan, *Solid State Communications* 13, 1413 (1973).
72. The Effect of Pressure on the Crystalline Electric Field Levels of Superconducting $\text{La}_{1-x}\text{Tb}_x\text{Al}_2$, R. P. Guertin, W. Boivin, J. E. Crow, A. R. Sweedler and M. B. Maple, *Solid State Communications* 13, 1889 (1973).

73. T_c 's - The High and Low of It, Bernd T. Matthias, Science and Technology of Superconductivity, Vol. I, eds. W. D. Gregory, W. N. Mathews, Jr. and E. A. Edelsack (Plenum Publishing Corp., N.Y., 1973), pp. 263-288.
74. Calorimetric Investigation of the Magnetic-Nonmagnetic Transition of Ce Impurities in Superconducting La,Th Alloys, C. A. Luengo, J. G. Huber, M. B. Maple and M. Roth, Physical Review Letters 32, 54 (Jan. 14, 1974).
75. Remarks on the Mutual Solubilities and Superconductivity of Hexaborides, Z. Fisk, A. C. Lawson and R. W. Fitzgerald, Materials Research Bulletin 9, 633 (May 1974).
76. Low Temperature Lattice Transformation of LaRu_2 , A. C. Lawson, U. Engel and K. Baberschke, Physics Letters A48, 107 (June 3, 1974).
77. Magnetic and Superconducting Properties of Niobium Oxides, H. R. Khan, Ch. J. Raub, W. E. Gardner, W. E. Fertig, D. C. Johnston and M. B. Maple, Materials Research Bulletin 9, 1129 (Sept. 1974).
78. Normal State Electrical Resistance Behavior and Superconducting Transition Temperatures in $(\text{La,Ce})\text{Ru}_2$ Alloys, A. C. Lawson, K. Baberschke and U. Engel, Physics Letters A49, 373 (Oct. 7, 1974).
79. Electrical and Magnetic Properties of Chromium Hydride, H. R. Khan, A. Knödler, Ch. J. Raub and A. C. Lawson, Materials Research Bulletin 9, 1191 (1974).
80. Heat Capacity of ThU Alloys at Low Temperatures, C. A. Luengo, J. M. Cotignola, J. G. Sereni, A. R. Sweedler and M. B. Maple, Proceedings of the 13th International Conference on Low Temperature Physics, Boulder, Colo., 1972, ed. K. D. Timmerhaus, W. J. O'Sullivan and E. F. Hannel (Plenum Press N.Y., London, 1974), pp. 585.
81. Heat Capacity Measurements on Isotopes of Molybdenum, R. Viswanathan, H. L. Luo and J. J. Engelhardt, Proceedings of the 13th International Conference on Low Temperature Physics, Boulder, Colo., 1972 ed. K. D. Timmerhaus, W. J. O'Sullivan and E. F. Hannel (Plenum Press, N.Y., London, 1974), pp. 445.
82. Ce Impurities in Th-based Superconducting Hosts, J. G. Huber and M. B. Maple, Proceedings of the 13th International Conference on Low Temperature Physics, Boulder, Colo., 1972, ed. K. D. Timmerhaus, W. J. O'Sullivan and E. F. Hannel (Plenum Press, N.Y., London, 1974), p. 579.

83. High Transition Temperature Ternary Superconductors, Bernd T. Matthias, Proceedings of the 13th International Conference on Low Temperature Physics, Boulder, Colo., 1972, ed. K. D. Timmerhaus, W. J. O'Sullivan and E. F. Hannel (Plenum Press, N.Y., London, 1974), p. 416.
84. Thermal Boundary Resistance between Pt and Liquid He³ at Very Low Temperatures, J. H. Bishop, A. C. Mota and J. C. Wheatley, Proceedings of the 13th International Conference on Low Temperature Physics, Boulder, Colo., 1972, ed. K. D. Timmerhaus, W. J. O'Sullivan and E. F. Hannel (Plenum Press, N.Y., London, 1974), p. 406.
85. Superconducting-Normal Phase Boundaries of (La,Th)Ce Systems, J. G. Huber, W. A. Fertig and M. B. Maple, Solid State Communications 15, 453 (1974).
86. High Pressure Synthesis of β -W-type Nb₃Te, John F. Cannon, Donald L. Robertson, H. Tracy Hall and A. C. Lawson, Journal of Physics and Chemistry of Solids 35, 1181 (1974).
87. Demagnetization of Rare Earth Ions in Metals Due to Valence Fluctuations, M. B. Maple and D. Wohlleben, Proceedings of the 18th Annual Conference on Magnetism and Magnetic Materials, AIP, N. Y. (1974), pp. 447-462.
88. Superconductivity in 1973, Bernd T. Matthias, International Journal of Quantum Chemistry 8, 499 (1974).
89. Pressure Enhanced Superconductivity in NbSe₂, T. F. Smith, R. N. Shelton and R. E. Schwall, Journal of Physics F: Metal Physics 4, 2009 (1974).
90. Synthesis of Superconducting Compounds by Thermolysis of Volatile Hydrides and Organometallic Compounds on Glowing Wires, G. N. Schrauzer and H. Prakash, Solid State Communications 14, 1259 (1974).
91. Superconductivity and Structural Behavior of Hexagonal MoN and Related Mo Compounds, J. M. Vandenberg and B. T. Matthias, Materials Research Bulletin 9, 1085 (1974).
92. Superconductivity in Two NaCl Structure Compounds: α -ZrP and ScS_{1+x}, A. R. Moodenbaugh, D. C. Johnston and R. Viswanathan, Materials Research Bulletin 9, 1671 (1974).
93. Superconductivity of TaV₂, Paul F. Schippnick and A. C. Lawson, Solid State Communications 15, 1797 (1974).

94. Superconductivity and Stability of Near-Equi-atomic V-Ru Compounds at High Pressure, T. F. Smith, R. N. Shelton, A. C. Lawson and C. W. Chu, Journal of Physics F: Metal Physics 4, 1423 (1974).
95. The Relation between Normal State Properties and T_c for Some Zr_2X Compounds, Z. Fisk, R. Viswanathan and G. W. Webb, Solid State Communications 15, 1797 (1974).
96. Magnetic Properties of $ZrZn_2$ under Pressure, J. G. Huber, M. B. Maple, D. Wohlleben and G.S. Knapp, Solid State Communications 16, 211 (Jan. 15, 1975).
97. New Superconducting Critical Temperatures and Fields, Bernd T. Matthias, Proceedings of 1974 Applied Superconductivity Conference, IEEE Trans. on Magnetics 11, #2, 154 (March 1975).
98. Pressure Dependence of the Superconducting Transition Temperature for Ternary Molybdenum Sulfides, R. N. Shelton, A. C. Lawson, and D. C. Johnston, Materials Research Bulletin 10, 297 (April 1975).
99. Search for Crystallographic Instability in Hexagonal Tungsten Bronzes, A. C. Lawson, Z. Fisk and H. R. Shanks, Physical Review B11, 4054 (May 15, 1975).
100. Isotope Effect in the Resistivity of Scandium Hydride, Z. Fisk and D. C. Johnston, Physical Letters 53A, 39 (May 19, 1975).
101. Pressure Dependence of T_c for the Transition Metals: bcc Solid Solution Alloys in the System Zr-Nb-Mo-Re, T. F. Smith and R. N. Shelton, Journal of Physics F: Metal Physics 5, 911 (May 1975).
102. Superconducting Properties of Singlet Ground State System $(LaPr)Sn_3$, R. W. McCallum, W. A. Fertig, C. A. Luengo, M. B. Maple, E. Bucher, J. P. Maita, A. R. Sweedler, L. Mattix, P. Fulde and J. Keller, Physical Review Letters 34, 1620 (June 30, 1975).
103. Electrical Resistivity of Ni-Cr Alloys, T. F. Smith, R. J. Tainsh, R. N. Shelton and W. E. Gardner, Journal of Physics F: Metal Physics 5, L96 (June 1975).
104. Superconductivity of $TaS_{2-x}Se_x$ Layer Compounds at High Pressure, T. F. Smith, R. N. Shelton and R. E. Schwall, Journal of Physics F: Metal Physics 5, 1713 (Sept. 1975).
105. Pressure Dependence of T_c and Phase Stability for V_3Si , R. N. Shelton and T. F. Smith, Materials Research Bulletin 10, 1013 (Oct. 1975).

106. The Effect of Pressure on the Superconducting and Crystallographic Transition of La_3S_4 , La_3Se_4 and La_3Te_4 , R. N. Shelton, A. R. Moodenbaugh, P. D. Dernier and B. T. Matthias, Materials Research Bulletin 10, 1111 (Oct. 1975).
107. Supraleiter, B. T. Matthias, Journal of Less Common Metals 43, 1 (Nov. -Dec. 1975).
108. Lattice Parameters and Superconductivity of the Compounds U_6Mn , U_6Fe , U_6Co and U_6Ni and Alloys between Them, John J. Engelhardt, Journal of Physics and Chemistry of Solids 36, 123 (1975).
109. Large Electron-Phonon Interaction but Low Temperature Superconductivity in LaB_6 , A. J. Arko, G. Crabtree, J. B. Ketterson, F. M. Mueller, P. F. Walch, L. R. Windmiller, Z. Fisk, R. F. Hoyt, A. C. Mota, R. Viswanathan, D. E. Ellis, A. J. Freeman and J. Rath, International Journal of Quantum Chemistry 9, 569 (1975).
110. Superconductivity of Some Binary and Ternary Transition-Metal Borides, J. M. Vandenberg, B. T. Matthias, E. Corenzwit and H. Barz, Materials Research Bulletin 10, 889 (1975).
111. Low Temperature Heat Capacity of TTF (TCNQ), R. Viswanathan and D. C. Johnston, Journal of Physics and Chemistry of Solids 36, 1093 (1975).
112. T_c and Its Pressure Dependence for Technetium-Based HCP Solid Solution Alloys, R. N. Shelton, T. F. Smith, C. C. Koch and W. E. Gardner, Journal of Physics F: Metal Physics 5, 1916 (1975).
113. Superconductivity in 1974, Bernd T. Matthias, International Journal of Quantum Chemistry 9, 579 (1975).
114. Effect of Pressure on the Superconducting Transition Temperature of $(\text{LaPr})\text{Sn}_3$ and $(\text{LaGd})\text{Sn}_3$, L. E. DeLong, R. W. McCallum and M. B. Maple, Proceedings of 14th International Conference on Low Temperature Physics, Vol. II (Superconductivity), ed. M. Krusius, M. Vuorio (North Holland Publishing Co., Amsterdam, 1975), pp. 541-544.
115. Thermodynamic Critical Field of the Singlet Ground State System $(\text{LaPr})\text{Sn}_3$, R. W. McCallum, C. A. Luengo, M. B. Maple and A. R. Sweedler, Proceedings of 14th International Conference on Low Temperature Physics, Vol. II (Superconductivity), ed. M. Krusius, M. Vuorio (North Holland Publishing Co., Amsterdam, 1975), pp. 537-540.

116. Correlations and Anticorrelations between Crystal Structures and Superconductivity, Bernd T. Matthias, Trans. American Crystallographic Association, Vol. 11, 103 (1975).
117. Superconductivity and Anharmonicity in V_3Si , T. F. Smith, T. R. Finlayson and R. N. Shelton, Journal of Less Common Metals 43, 21 (1975).
118. Comment on "X-Ray-Diffuse-Scattering Evidence for a Phase Transition in Tetrathiafulvalene Tetracyanoquinodimethane (TTF-TCNQ)," B. T. Matthias, Physical Review Letters 36, 343 (Feb. 1976).
119. Superconductivity in Rare Earth Molybdenum Selenides, R. N. Shelton, R. W. McCallum and H. Adrian, Physics Letters 56A, 213 (Mar. 22, 1976).
120. Electrical Resistivity and Magnetic Susceptibility of $ThOs_2$, A. C. Lawson, D. C. Johnston and B. T. Matthias, Physics Letters 56A, 209 (Mar. 22, 1976).
121. Thermodynamic Study of Structural and Superconducting Transitions in a V_3Si Single Crystal, R. Viswanathan and D. C. Johnston, Physical Review B13, 2877 (April 1, 1976).
122. Phonon Properties of A-15 Superconductors Obtained from Heat Capacity Measurements, G. S. Knapp, S. D. Bader and Z. Fisk, Physical Review B13, 3783 (May 1976).
123. The deHaas van Alphen Effect and the Fermi Surface of LaB_6 , A. J. Arko, G. Crabtree, D. Karim, F. M. Mueller, L. R. Windmiller, J. B. Ketterson and Z. Fisk, Physical Review 13B, 5240 (June 15, 1976).
124. Specific Heat of a New Metastable Phase of Scandium-Chromium, R. W. McCallum, D. C. Johnston, M. B. Maple and B. T. Matthias, Materials Research Bulletin 11, 781 (July 1976).
125. Growth of YB_6 Single Crystals, Z. Fisk, P. H. Schmidt and L. D. Longinotti, Materials Research Bulletin 11, 1019 (Aug. 1976).
126. Obstacles to Superconductivity in CsCl Phases, B. T. Matthias, E. Corenzwit, J. M. Vandenberg, H. Barz, M. B. Maple and R. N. Shelton, Journal of Less Common Metals 46, 339 (1976).
127. Superconductivity in α -Phase Alloys of Cu, Ag and Au, R. F. Hoyt and A. C. Mota, Solid State Communications 18, 139 (1976).

128. Low Temperature Heat Capacity of LaRu_2 by a.c. Technique, R. Viswanathan, A. C. Lawson and C. S. Pende, Journal of Physics and Chemistry of Solids 37, 341 (1976).
129. The Effect of Crystal Field Splittings on the Electrical Resistivity of NdB_6 , Z. Fisk, Solid State Communications 18, 221 (1976).
130. Superconducting and Normal State Properties of $\text{Li}_{1+x}\text{Ti}_{2-x}\text{O}_4$ Spinel Compounds. I. Preparation, Crystallography, Superconducting Properties, Electrical Resistivity, Dielectric Behavior, Magnetic Susceptibility, D. C. Johnston, Journal of Low Temperature Physics 25, 145 (1976).
131. Superconducting and Normal State Properties of $\text{Li}_{1+x}\text{Ti}_{2-x}\text{O}_4$ Spinel Compounds. II. Low Temperature Heat Capacity, R. W. McCallum, D. C. Johnston, C. A. Luengo and M. B. Maple, Journal of Low Temperature Physics 25, 177 (1976).
132. Saturation of the High Temperature Normal State Electrical Resistivity of Superconductors, Z. Fisk and G. W. Webb, Physical Review Letters 36, 1084 (1976).
133. Anharmonicity as an Explanation for Anomalous Resistance of High- T_c Superconductors, P. B. Allen, J. C. K. Hin, W. E. Pickett, C. M. Varma and Z. Fisk, Solid State Communications 18, 1157 (1976).
134. Ferroelectricity: Why Did It Take So Long?, Bernd T. Matthias, Ferroelectrics (in press).
135. Lattice Instability in Non-A-15 Superconductors, A. C. Lawson and R. N. Shelton, Ferroelectrics (in press).
136. Mode Softening and High Superconducting Transition Temperatures in Some A-15 Compounds, G. S. Knapp, S. D. Bader and Z. Fisk, Ferroelectrics (in press).
137. Superconducting and Normal State Properties of $\text{Ag}_{1-x}\text{Sn}_{1+x}\text{Se}_{2-y}$, D. C. Johnston and H. Adrian, Journal of Physics and Chemistry of Solids (in press).
138. Measurement of the Pressure Dependence of T_c for Superconducting Spinel Compounds, R. N. Shelton, D. C. Johnston and H. Adrian, Solid State Communications (in press).
139. Superconductivity of a New Metastable Phase of Scandium-Chromium, J. M. Vandenberg, B. T. Matthias, E. Corenzwit and H. Barz, Journal of Solid State Chemistry (in press).

140. Superconductivity, Bernd T. Matthias, Critical Materials Problems in Energy Production (Academic Press, 1976) (in press).
141. The Effect of High Pressure on Superconducting Ternary Molybdenum Chalcogenides, R. N. Shelton, Proceedings of the Conference on Superconductivity in d- and f-Band Metals, ed. David H. Douglass, Rochester, N. Y. (April-May, 1976) (in press).
142. Calorimetric Observation of a Phase Transition in the Superconducting State in $Gd_{1.2}Mo_6Se_8$, R. W. McCallum, D. C. Johnston, R. N. Shelton and M. B. Maple, Proceedings of the Conference on Superconductivity in d- and f-Band Metals, ed. David H. Douglass, Rochester, N. Y. (April-May, 1976) (in press).
143. Some Surprises in Superconductivity, Bernd T. Matthias, Proceedings of the Conference on Superconductivity in d- and f-Band Metals, ed. David H. Douglass, Rochester, N. Y. (April-May, 1976) (in press).
144. Inelastic Neutron Scattering Studies of the Phonon Spectra of Chevrel Phase Superconductors, S. D. Bader, S. K. Sinha and R. N. Shelton, Proceedings of the Conference on Superconductivity in d- and f-Band Metals, ed. David H. Douglass, Rochester, N. Y. (April-May, 1976) (in press).
145. Saturation of the High Temperature Normal State Electrical Resistivity of Superconductors, Z. Fisk and G. W. Webb, Proceedings of the Conference on Superconductivity in d- and f-Band Metals, ed. David H. Douglass, Rochester, N. Y. (April-May, 1976) (in press).
146. Low Temperature Specific Heat and Superconductivity of Alpha-Phase Au-Ga Alloys, R. F. Hoyt, A. C. Mota and C. A. Luengo, Physical Review B (in press).
147. Catalysis Versus Superconductivity, Bernd T. Matthias, Proceedings of the Willard Libby Workshop (in press).
148. Symmetries of Superconducting Sulfides, Bernd T. Matthias, International Journal of Quantum Chemistry (in press).
149. Low Temperature Heat Capacity of Small Nb_3Sn Polycrystals by ac Calorimetry, R. Viswanathan and D. C. Johnson, Journal of Low Temperature Physics (in press).
150. Normal-State Properties of Some Superconducting Ternary Molybdenum Sulfides, R. Viswanathan and A. C. Lawson, Indo-Soviet Conference on Solid State Materials, Bangalore, India (in press).

151. Pressure Induced Loss of Ferromagnetism in UPt, J. G. Huber, M. B. Maple and D. Wohlleben, International Journal of Magnetism (in press).
152. Comment on "Influence of Composition on the Superconducting Transition Temperature of Alloys with the A-15 Structure," G. W. Webb and B. T. Matthias, Solid State Communications (in press).
153. Dependence of the Superconducting Transition Temperature on Electron per Atom Ratio and Lattice Deformation in Noble Metal Alloys, A. C. Mota and R. F. Hoyt, Solid State Communications (in press).

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Brian C. Sales	Valence Fluxuations on Rare Earth Ions November 23, 1974
David C. Johnston	Superconducting and Normal State Properties of Several Ternary Titanium Oxides January 6, 1975
Arnold R. Moodenbaugh	Superconductivity of Some NaCl Structure Sulfides, Selenides and Phosphides July 1, 1975
Robert N. Shelton	Investigation Into the Effect of High Pressure on Superconducting Ternary Molybdenum Chalcogenides December 6, 1975

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COUPLING

Contract: AFOSR F44620-72-C-0017

Date: 10/1/75 - 9/30/76

1. High Transition Temperature Superconducting Materials

- a. Bernd T. Matthias, University of California, San Diego
- b. Consultation with other government agencies.
- c. National Bureau of Standards, Washington, D. C. New superconducting critical temperatures and fields.
- a. Bernd T. Matthias, University of California, San Diego
- b. Consultation with other government agencies.
- c. Distinguished Lectures, Joint Center for Materials Science including Los Alamos Scientific Laboratory, Sandia Laboratory, Air Force Weapons Laboratory plus University of New Mexico, New Mexico Institute of Mining and Technology and New Mexico State University. Superconducting materials, their use now and applications for the future.
- a. Bernd T. Matthias, University of California, San Diego
- b. Consultation with other government agencies.
- c. U. S. Army Symposium on Ultra High Pressure Phenomena, Rensselaerville, N. Y. Applications of ultra high pressures to superconductors and the applications of the resulting new superconducting materials.
- a. Bernd T. Matthias, University of California, San Diego
- b. Consultation with other government agencies, including two branches of DOD (Army and Navy).
- c. Executive Technical Development Program. Office of Special Programs, Polytechnic Institute of New York. General discussion on superconductivity, ferroelectricity and magnetism.

2. Other Topics

- a. Bernd T. Matthias, Zachary Fisk and A. C. Lawson, Univ. of Calif., San Diego
- b. The International Conference on Low Lying Lattice Vibrational Modes and Their Relationship to Superconductivity and Ferroelectricity, San Juan, Puerto Rico
- c. Phase transitions and their role in ferroelectricity, superconductivity and magnetism.
- a. Bernd T. Matthias, Zachary Fisk and A. C. Lawson, Univ. of Calif., San Diego
- b. 1976 d- and f-band Conference, Rochester, New York
- c. New magnetic superconductors.
- a. Bernd T. Matthias, University of California, San Diego
- b. 1976 Applied Superconductivity Conference, Stanford University, Stanford, California
- c. New superconductors, their applications now and in the future.

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Contract: AFOSR F44620-72-C-0017

Date: 10/1/74 - 9/30/75

1. High Transition Temperature Superconducting Materials

- a. Bernd T. Matthias, University of California, San Diego
- b. Consultation with other government agencies
- c. Los Alamos Scientific Laboratories, Los Alamos, New Mexico--The problem of improving the basic properties of present superconducting materials for use in superconducting cables continues being discussed with various groups of researchers at Los Alamos Scientific Laboratories. These discussions have resulted in the development of a new method of synthesis for Nb_3Ge in bulk form with transition temperatures of 22.5°K. A major part of the coupling is, unfortunately, at present available only in classified form.
- a. Bernd T. Matthias, University of California, San Diego
- b. Conference
- c. 1974 Applied Superconductivity Conference, Oakbrook, Illinois. New superconducting critical temperatures and fields.
- a. Bernd T. Matthias, University of California, San Diego
- b. Picatinny Arsenal, John W. Gregorits and Leon W. Saffian; Naval Shipyard, Research and Development, Robert J. Wolfe; CIA, Corroll W. Morrow, and other government agencies. training program.
- c. Executive Technical Development Program. Office of Special Programs, Polytechnic Institute of New York. General discussion on superconductivity, ferroelectricity and magnetism.
- a. Bernd T. Matthias
- b. Conference and interaction with various other agencies.
- c. American Physical Society Meeting, Anaheim, California. Applications of superconductors.
- a. Bernd T. Matthias
- b. Invited lecture
- c. Naval Research Laboratory, Washington, D. C. New superconductors and instabilities.

Coupling

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- a. Bernd T. Matthias
- b. Invited lecture
- c. Applied Physics Colloquium, Johns Hopkins University, Silver Spring, Maryland. Properties and applications of superconductors.
 - a. A. C. Lawson
 - b. Colloquium
 - c. Pomona College, October 1974 High Transition Temperatures and Lattice Instabilities

2. Other Topics

- a. Bernd T. Matthias, University of California, San Diego
- b. Conference
- c. Resource Conference on Cu, University of California, San Diego. Copper shortage.
 - a. Bernd T. Matthias
 - b. Colloquium
 - c. Los Alamos Scientific Laboratories, Los Alamos, New Mexico Physics of plutonium.
 - a. Bernd T. Matthias
 - b. Conference, Leuven, Belgium (Keynote speaker)
 - c. This conference was a report to ERDA on the electronic properties of solids under high pressure.
 - a. Bernd T. Matthias
 - b. Colloquium
 - c. Los Alamos Scientific Laboratories, Theoretical Division, classified.
 - a. Zachary Fisk
 - b. sample preparation
 - c. Nb₃Sn samples for specific heat measurements, Dr. Gordon Knapp, Argonne National Laboratory Argonne, Illinois

Coupling

Date: 10/1/74 - 9/30/75

- a. Zachary Fisk and A. C. Lawson
- b. collaboration and x-ray measurements
- c. Search for Crystallographic Instability in Hexagonal Tungsten Bronzes,
H. R. Shanks, Ames Laboratory USAiC, Ames, Iowa
- a. D. C. Johnston, A. R. Moodenbaugh and A. C. Lawson
- b. sample preparation and collaboration
- c. Professor John Cannon, Brigham Young University, Provo, Utah
synthesis of new superconductors under high pressures.
- a. R. N. Shelton
- b. Talk at meeting
- c. APS General Meeting, Denver, Colorado March 1975 Pressure Dependence of the
Superconducting Transition Temperature for Ternary Molybdenum Sulfides

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- a. Bernd T. Matthias, University of California, San Diego
 - b. Consultation with other government agencies
 - c. Los Alamos Scientific Laboratories, Los Alamos, New Mexico--The problem of improving the basic properties of present superconducting materials for use in superconducting cables have been discussed with various groups of researchers at Los Alamos Scientific Laboratories. These discussions have resulted in the development of a new method of synthesis for Nb_3Ge in bulk form with transition temperatures of 22.5°K.
-
- a. Bernd T. Matthias, University of California, San Diego
 - b. Symposium
 - c. Marshall Space Flight Center, Huntsville, Alabama--Discussed the role of superconducting metallurgy in zero gravity fields.
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- a. Bernd T. Matthias, University of California, San Diego
 - b. Conference
 - c. American Academy of Arts and Sciences, San Francisco, Materials Achievements in the Enhancement of Our Health, Safety and Environment: Looking Ahead--Discussed the future difficulties encountered in energy and ecology which can be alleviated to a large extent by a superconducting technology.
-
- a. Bernd T. Matthias, University of California, San Diego
 - b. Conference
 - c. Israel Scientific Research Conferences, Haifa, Israel--Discussions including the final "putting to rest" of any high temperature organic superconductivity.

2. High Critical Fields in Superconductors

- a. Bernd T. Matthias, University of California, San Diego
- b. Conference
- c. Grenoble, France--The high critical fields of the new sulfides are now being verified from Europe to the United States. As a consequence, there may be rather decisive changes in the future applications of superconducting materials.

COUPLING

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1. Superconductivity

- a. Lt. Col. Edward Daggit, U. S. Army Armament Command, Rock Island, Ill.; Allen M. Moss, Theodore W. Stevens, Robert Leonardi, U. S. Army, Picatinny Arsenal, N. J.; Raymond F. Siewert and Samuel L. Taffel, Naval Air Systems Command.
- b. Discussion
- c. Executive Technical Development Program, Office of Special Programs, Polytechnic Institute of New York. General discussion on the applications of superconductivity

2. Superconducting Accelerators

- a. Los Alamos Scientific Laboratories, Inauguration of the Linear Accelerator
- b. Presentation and discussion
- c. The problems involved in the application of superconductors for magnets and cavities.

3. Applications for High Transition Temperature Superconducting Materials

- a. ARPA Workshop for Superconducting Technology
- b. Presentation and discussion
- c. A major part of the meeting was taken up by arguments on "organic superconductors." In the meantime, the then prevailing skepticism has been more than justified.

COUPLING

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1. Crystallographic Instabilities and High Temperature Superconductivity

- a. Professor Bernd T. Matthias; University of California, San Diego
- b. Testimony before Subcommittee on Science, Research and Development
for hearings on Energy Research and Development, Rayburn House Office
Bldg., Washington, D. C. May 23, 1972 "Electric Power Transmission:
The Use of Superconductors"

- a. Professor Bernd T. Matthias; University of California, San Diego
- b. Conference: National Commission on Materials Policy, Lake Arrowhead,
California June 12 - 16, 1972 "Materials for Electricity and
Magnetism, Advanced Material Usage in the Southwest"

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) During the past five years we have made four distinct advances in the science of superconductivity: (1) We have discovered many new superconductors, including lithium-titanate ($T_c = 13.7K$) and numerous Chevrel phases ($T_c = 15.2K$ lead-molybdenum-sulfide). The latter are remarkable not only for their extraordinarily high critical fields, which are close to 700 kg in some cases, but also for the fact that really high critical temperatures have for the first time been discovered in non-cubic materials. At the same time, the old electron-per- <i>were discovered</i> <i>cont. next page</i>			

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atom rules do not seem to work for the Chevrel phases. We have also discovered superconductivity in many related oxides, sulfides and selenides. (2) We have obtained overwhelming evidence for a connection between moderate-to-high-temperature superconductivity and low temperature structural instability. Our work on both the occurrence and the pressure dependence of superconductivity and lattice instability in zirconium-vanadium, hafnium-vanadium, lanthanum-ruthenium, ruthenium-vanadium, copper-molybdenum-sulfide, copper-molybdenum-selenide, zinc-molybdenum-sulfide, gold-zinc, lanthanum-sulfide, and lanthanum-selenide has shown that the connection between the two phenomena is very general. (3) We have developed an empirical correlation between the shape of electrical resistivity versus temperature curve of a given superconductor and its transition temperature. Despite our incomplete understanding of its nature, we have found this correlation useful in predicting superconductivity in some cases. (4) We have extrapolated to the transition temperatures of magnesium and gold (5×10^{-4} and 2×10^{-4} K, respectively). This information is fundamental for our understanding of the periodic system vis-a-vis superconductivity.

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